Responses of Carbon Accumulation to Microtopography and Fire: Complex Interactions in Boreal Peatlands

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Combustion

Introduction

Peatland ecosystems cover an estimated 3-4 % of the earth's land surface (Gorham 1991). Gorham (1991) estimated that boreal and subarctic peatlands, collectively, represent a 455 Pg carbon pool and are sequestering atmospheric C at 23 g m^{-2} yr^{-1}, which extrapolates to a global net sink of 76 Tg yr^{-1}. However, the results of Turetsky *et al.* (2002) cast doubt on the magnitude of this claimed sink due to exclusion of disturbance in previous estimates.

Fire compromises the C storage capacity of peatlands directly through combustion of biomass. Although some current estimates of peatland C balance have taken into account the direct effects of fire, none included spatial variability in plant species composition and associated fire response, which could complicate assessments of fire effects. Using the excess ash approach of Turetsky and Wieder (2001), we quantified variation in organic matter lost due to combustion in the Chisholm, Alberta fire of 2001 between microtopographic positions (hummocks vs. hollows) in an ombrotrophic bog peatland. ***Based on field observations, we hypothesized that for peatlands with considerable microtopography, hummocks will be burned less extensively than hollows.***

Figure 1. Post-fire bog conditions. Note the extensive charring of hollows relative to hummocks.

Methods

Within a bog burned in the 2001 Chisholm, Alberta fire (***Figure 1***), 20-cm long peat cores were collected randomly from 40 hummocks and hollows approximately 3 days post-fire. From each core, the upper burned portion was collected, along with 5 cm of the underlying unburned section. Each sample was dried, weighed, and homogenized, and ash concentration was determined for three subsamples of each burned and unburned portion. Assuming uniform ash concentration throughout an unburned peat column, organic matter lost during combustion was calculated (*c.f.* Turetsky and Wieder 2001) for hummocks and hollows and analyzed using a nested analysis of variance.

Results and Discussion

A significant microtopography effect (F=18.21; df=4,180; ***p<0.0001***) revealed almost twice as much organic matter was lost from hollows (2.76 0.33 kg C m^{-2}; n=36) than hummocks (1.45 0.11 kg C m^{-2}; n=39), an effect most likely related to differences in species composition. Drought-avoiding hummock species, namely *S. fuscum*, form dense mats of individuals capable of retaining water, allowing the hummock to remain relatively moist even under periods of high stress (Titus *et al.* 1983, Rydin and McDonald 1985). *Sphagnum* species in hollows are more loosely arranged; water availability usually is relatively high because of closer proximity of the water table (Titus *et al.* 1983, Rydin and McDonald 1985). However, during extended dry periods, hollow species can become quite desiccated. Hummocks are therefore less likely to burn because they remain relatively moist during fire, while hollows will combust more readily when the ambient water is evaporated during fire.

Spatial variability in species composition and water status contribute to considerable spatial variation in C release during fire. The results support the hypothesis that significant variation exists within peatlands in degree of combustion during relatively uniform fire conditions. Comparison of carbon emissions from six scenarios modeling the ratio of peatland area experiencing heavy (*i.e.*, hollow) vs light (*i.e.*, hummock) combustion rates gave a mean C-loss rate of 2.1 0.4 kg m^{-2}, releasing 3.1 0.5 Tg C annually from boreal Canadian peatlands (***Table 1***). Future C balance models need to take this variability into account when making accurate assessments of overall C loss during peatland fire.

Table 1. Peatland C losses under six combustion scenarios.

Combustion (heavy:light) ratio (%)	Relative combustion	Area burned ($km^2 \cdot year^{-1}$)[a]	Estimated C loss ($Tg \cdot year^{-1}$)[b]	Combined C loss ($Tg \cdot year^{-1}$)	Emission rate ($kg\ C \cdot m^{-2}$)[c]
30:70	Heavy	441±18	1.2±0.2	2.7±0.4	1.8±0.3
	Light	1029±41	1.5±0.2		
40:60	Heavy	588±24	1.6±0.3	2.9±0.4	2.0±0.4
	Light	882±35	1.3±0.2		
50:50	Heavy	735±30	2.0±0.3	3.1±0.5	2.1±0.4
	Light	735±30	1.1±0.1		
60:40	Heavy	882±35	2.4±0.4	3.3±0.5	2.2±0.4
	Light	588±24	0.9±0.1		
70:30	Heavy	1029±41	2.8±0.5	3.5±0.5	2.4±0.4
	Light	441±18	0.6±0.1		
Mean				3.1±0.5	2.1±0.4

Note: No differences were assumed in combustion between bog and permafrost peatlands (Turetsky and Wieder 2001) and in total C emissions between bogs and fens when above- and below-ground combustions were taken into account (Zoltai et al. 1998). Values represent mean ± SE.

[a]Based on percentage of 1470 ± 59 $km^2 \cdot year^{-1}$ burned (cf. Turetsky et al. 2002).

[b]Area burned multiplied by estimated carbon loss per unit area ($kg \cdot m^{-2}$) for respective degree of combustion: Heavy, 2.8 ± 0.33; Light, 1.5 ± 0.1.

[c]Combined C loss divided by total area burned (1470 ± 59 $km^2 \cdot year^{-1}$; cf. Turetsky et al. 2002).

from Benscoter and Wieder 2003

Peat Accumulation

Introduction

Disproportionate rates of production relative to decomposition result in organic carbon accumulation in peatlands. Accumulation rates are species dependent, as different species have different photosynthetic capacities (Vitt 1990) and rates of decomposition (Turetsky and Crow *in review*), resulting in accumulation differences based on species dominance. Site conditions, such as degree of water saturation, also govern peat accumulation (Vitt 1990). The microtopographic gradient in bogs represents the interaction of site and species factors on peat accumulation, with high, dry hummocks dominated by *S. fuscum* and low, wet hollows dominated by *S. angustifolium*.

Fire alters peat accumulation by removing surface vegetation and resetting the successional pattern. Through relay floristic succession, different species assume dominance at different stages and for different durations, altering peatland function. Differences in fire severity result in different successional starting points, causing peat accumulation differences due to the structure and duration of post-fire vegetation communities. ***We hypothesize hummocks have greater peat accumulation shortly post-fire due to faster returns to pre-fire vegetation composition than hollows, with the degree of difference diminishing over time.***

Methods

Ten 50-cm long peat cores were collected from hummocks and hollows from two historically burned bogs near Sinkhole Lake (60 ysf) and Athabasca (~ 40 ysf), Alberta. Cores were sectioned at 1-cm intervals, dried, and weighed, and organic matter content was determined, followed by calculations of post-fire bulk density, column depth, and peat accumulation (rate and total). Results were analyzed using one-way ANOVA's to assess microtopographic and site (recovery time) differences.

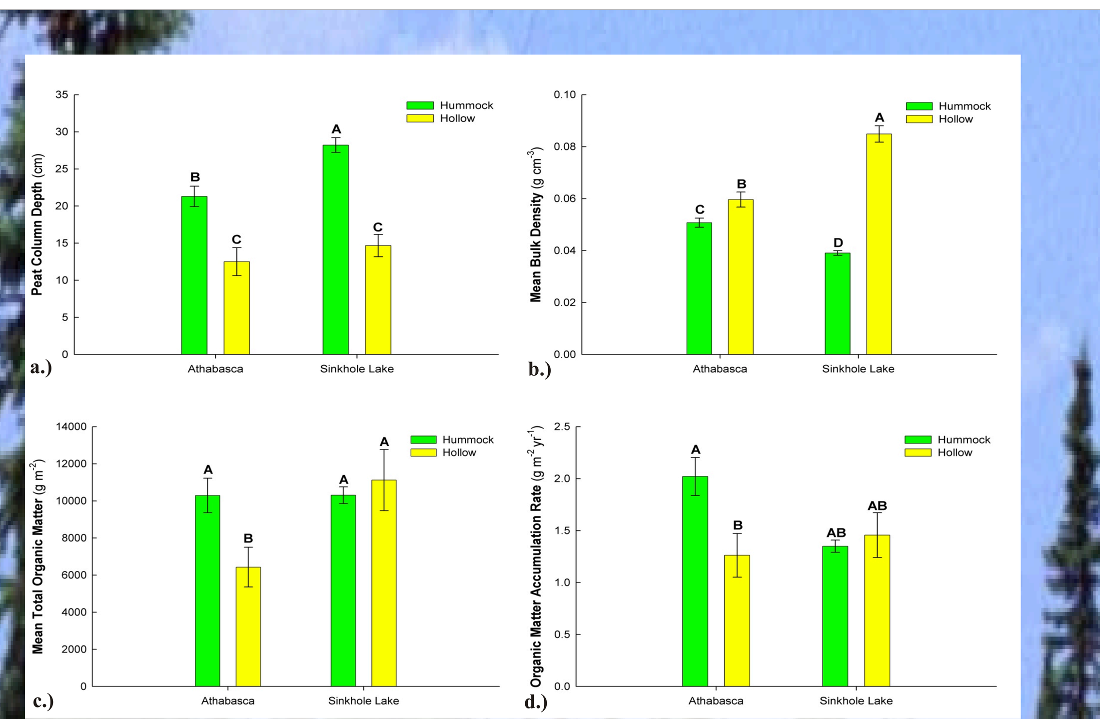

Figure 2. Bar graphs of mean peat column depth (a), mean bulk density (b), mean total organic matter (c) and mean organic matter accumulation rate (d) SE for hummocks and hollows from two bogs in Alberta, Canada. Bars with different labels are significantly different (=0.05) based on Tukey's HSD *a-posteriori* comparisons.

Results and Discussion

Mean column depth (***Figure 2a***) and mean bulk density (***Figure 2b***) showed an inverse relationship between hummocks and hollows. Hummocks had greater column depth and lower mean bulk density than hollows, and the magnitude of the difference between features increased between sites (over time). Mean total organic matter (***Figure 2c***) illustrates a trade-off between column depth and bulk density. When the difference in column depth between hummocks and hollows is greater than their difference in mean bulk density, hummocks have more total organic matter. When the differences are approximately equal, total organic matter is equal between features. A similar shift in peat accumulation rate (***Figure 2d***) occurs over time as well. At 40 yrs (Athabasca), hummocks have a greater accumulation rate than hollows. By 60 yrs (Sinkhole Lake), the hummock rate has decreased and the hollow rate increased to an intermediate level, with both features accumulating peat at the same rate.

We project the pattern of peat accumulation post-fire is species dependent and therefore changes over time as vegetation succession occurs (***Figure 3***). The rate of change is dependent on local fire severity and its effect on vegetation composition and succession.

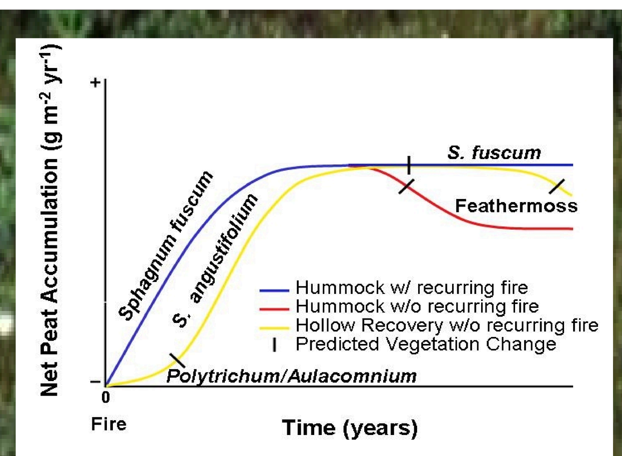

Figure 3. Conceptual model of the post-fire relationship between peat accumulation and vegetation composition.

from Benscoter 2002

Post-Fire Recovery

Introduction

Fire has substantial affects on boreal peatland structure and function. Approximately 1,470 km^2 of peatlands burn annually in western Canada (Turetsky *et al.* 2002), directly releasing 3.1 Tg C to the atmosphere due to combustion (Benscoter and Wieder 2003). Perturbation of the peatland carbon balance is exacerbated further through indirect post-fire carbon losses such as increased decomposition and diminished photosynthetic production. The cumulative impact of these C losses may have far reaching affects on temporal net peat accumulation. However, assessments of peatland C sink status and C pool size have neglected to account for these affects.

Net peatland function changes post-fire as a function of vegetation recovery through succession, as rates of production and decomposition, and therefore peat accumulation, are species dependent. Upon vegetation re-establishment, peat accumulation will return functionally, but accumulation rates will change over time as succession occurs. ***Therefore, we hypothesize net peat accumulation will recover functionally post-fire quickly (<10 yr), but net accumulation temporally (return to pre-fire C pool) will be greatly extended.***

Methods

Bog peatlands representing various fire recovery times (1-102 ysf) were identified based on know historical fire occurrence (Alberta Large Fire Database; Alberta Sustainable Resource Development) or dendrochronological analysis of *Picea mariana* from the site (Bone *unpublished data*). Five plots were established along a stratified random transect through each site and species-specific surface production was assessed for 50 cranked wires in each plot using the methods of Clymo (1970). Mean production weighted by species composition and abundance were calculated for each site and analyzed as a function of time using regression analysis to determine the post-fire peat accumulation rate recovery trajectory.

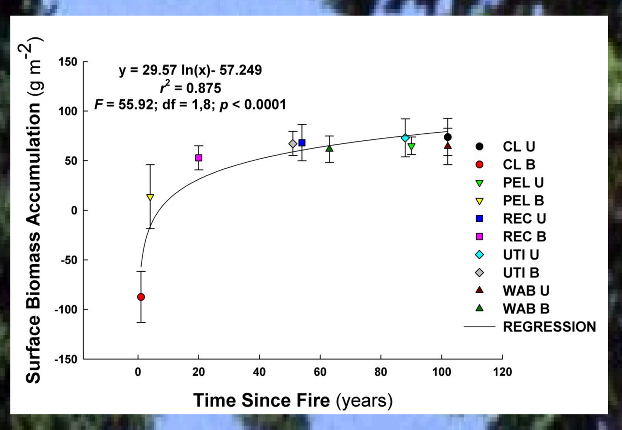

Figure 4. Post-fire net peat accumulation recovery trajectory for boreal Canadian bog peatlands.

Results and Discussion

Net peat accumulation rate showed a logarithmic temporal recovery trajectory post-fire, with positive functional net peat accumulation being achieved in approximately eight years (***Figure 4***). However, it may take considerable more time for the C pool to rebound from the C balance deficit caused by eight years of negative net production. By 20 yrs post-fire, the rate of peat accumulation begins to asymptotically level off, as peat accumulation rates are statistically similar between sites with 20 and 102 years of recovery.

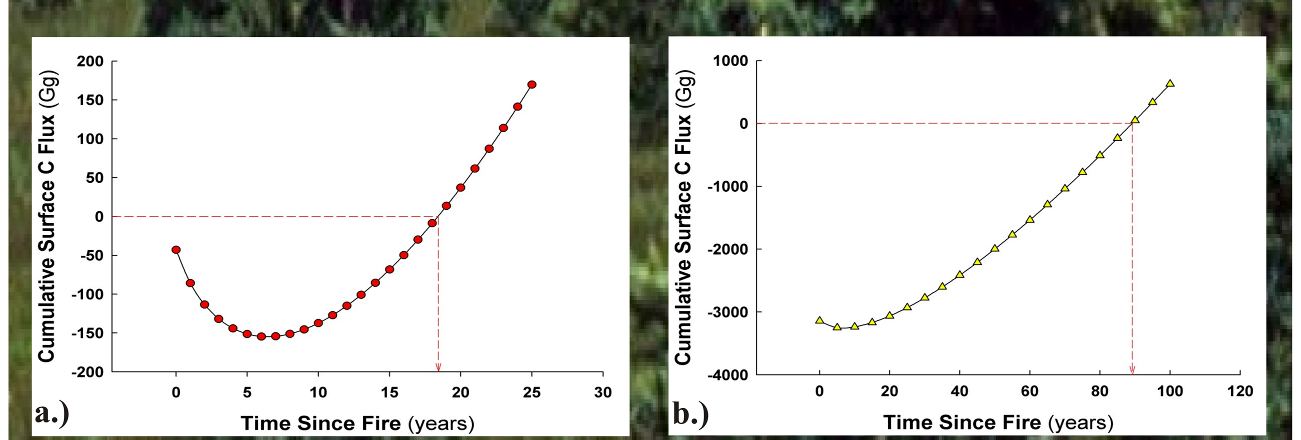

Figure 5. Peatland carbon pool recovery projections based on scenarios modeling indirect fire effects only (a) and including 3.1 Tg of direct C emissions during combustion (*see 'Combustion' column*; b). Models include only surface C flux projections and are based on one fire season cohort (1470 km^2 burned peatland). Dotted line indicates point at which C pool returns to pre-fire magnitude.

Implications

Using the derived recovery equation, models of cumulative C pool change over time were generated using only surface processes (no bulk column decomposition) for one fire season cohort, analyzing scenarios involving only indirect fire effects (change in production; ***Figure 5a***) and with the addition of direct emissions due to combustion (***Figure 5b***). Temporal returns to positive net peat accumulation (return to pre-fire C pool size) required approximately 18 yrs when only the indirect effects of fire were modeled and 80+ yrs when C emissions from combustion were included

Conclusions

Peatlands are complex ecosystems with many processes and patterns that are different than those occurring in upland areas. The take-home messages of these studies are:

1) Most peatland functions and processes are species-dependent, and therefore governed by the composition of the vegetation, which changes through relay floristic succession.
2) Fire severity is heterogeneous through a peatland, resulting in hollows burning to a greater degree than hummocks. Therefore, the ratio of high to low severity combustion affects total peatland C emissions during fire.
3) Post-fire peat accumulation and its properties vary spatially and temporally due to variation in vegetation composition and the inherent characteristics thereof.
4) Although production stability is achieved relatively quickly post-fire (~ 8 yr), return to pre-fire C pool size can take an order of magnitude longer.

Future attempts to assess and model the peatland C balance must take the direct and indirect affects of fire and functional temporal scale into account in order to make accurate assessments of peatland C status and terrestrial carbon cycling.

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